Fuel Dispersal Interactions (FDI) Package Users' Guide

The FDI (Fuel Dispersal Interactions) package models both low-pressure molten fuel ejection from the RPV into the reactor cavity and high-pressure molten fuel ejection from the RPV with the possibility of dispersion of the debris over multiple containment volumes and surfaces. The possibility of steam explosions from fuel-coolant interactions is not considered. New in MELCOR 1.8.5 is a FDI sensitivity coefficient used to control the numerical order in which oxygen or steam is used to oxidize DCH metals. This parameter affects the amount of hydrogen that results from burning DCH materials in steam/oxygen atmospheres.

This document includes a brief description of the models employed, the input format, sample input, sensitivity coefficients, plot variables and control functions. Details on the models can be found in the FDI Reference Manual.

Contents

1. Model Description

The capabilities of the FDI package are briefly summarized in this section. More details will be provided in the FDI package reference manual.

Two types of phenomena are treated in the FDI package:

(1) low-pressure molten fuel ejection from the reactor vessel, LPME, and

(2) high-pressure molten fuel ejection from the reactor vessel, HPME, (direct containment heating).

There is currently no plan to model steam explosions within or outside the FDI package in MELCOR.

During low-pressure ejection, heat is transferred from the molten fuel to the water pool (if present in the associated control volume) as it breaks up and falls to the cavity floor. The heat transfer normally occurs by radiation, but a convective lower bound is also included. All of the energy transfer from the molten fuel is used to boil the pool water (sensible heating is assumed to be unimportant). If no pool is present, material passes through FDI without any energy removal.

If the velocity of the molten debris ejected from the reactor vessel exceeds a critical value, prescribed by an adjustable sensitivity coefficient, or if the user has invoked the stand-alone option for high pressure melt ejection modeling, then the FDI will be treated by the high-pressure model instead of the low-pressure model. The parametric high-pressure model requires user input to control both the distribution of debris throughout the containment and the interaction of the hot debris with the containment atmosphere and heat structure (deposition) surfaces. The processes modeled include oxidation of the metallic components of the debris (Zircaloy, aluminum and steel are considered) in both steam and oxygen, surface deposition of the airborne debris by trapping or settling and heat transfer to the atmosphere and deposition surfaces. First-order rate equations with user-specified time constants for oxidation, heat transfer and settling are used to determine the rate of each process. Heat transfer to structure surfaces is limited by a heat transfer coefficient specified by a sensitivity coefficient. Debris entering the CAV package, either by direct deposition or settling from the atmosphere, is not treated by the FDI package; hence, the oxidation and heat transfer on deposition surfaces refers only to heat structure deposition surfaces. If a pool of water exists in the reactor cavity at the time of debris ejection, then the model ejects the water into the droplet field (fog) of the atmosphere at a rate proportional to the rate of injection of the debris into the pool.

If HPME model user input is absent, the HPME model will be disabled and all FDI events will be treated by the LPME model irrespective of ejection conditions. No direct

containment heating will occur if the user has not included the necessary input on records FDInn04 and FDInnmm.

2. User Input

The user input for the FDI package is described in this section. MELGEN input is described first, followed by MELCOR input, which is a subset of MELGEN input. The FDI model may be applied at several melt ejection locations within a problem; however, in the vast majority of problems the model is applied at only one location. An FDI location is basically a location at which debris may be ejected from a reactor vessel upon failure or a location at which debris is introduced from a source external to the problem domain. In most full-scale reactor calculations the model is applied in the CVH control volume beneath the reactor vessel lower head (specified by entry ICVCAV on COR record CORLHDii). In stand-alone HPME analyses of direct containment heating issues, the model is applied in the volume immediately downstream of the debris source.

For reactor plant calculations that may lead to vessel failure at relatively high pressure, users should provide input for both the LPME and HPME models. The LPME model input designates the FDI location, which is normally the reactor cavity CVH volume number as discussed above, the transfer process number associated with debris transfer from the COR package to the FDI package, the CAV cavity number and the associated transfer process number for debris transferred from the FDI package to the CAV package. The HPME model input specifies volumes into which the debris may be injected and parameters for controlling the interaction between the debris and its surroundings. If HPME input is not provided, then the LPME model will be invoked irrespective of the differential pressure between the reactor vessel and the reactor cavity during the melt ejection.

The FDI model may also be used to explore direct containment heating issues and experiments which do not involve actual modeling of the reactor (the COR package). In such cases, the HPME model is used in stand-alone mode, and the high-pressure debris source to the model is provided by the user. In stand-alone HPME calculations, the LPME model is inactive, and the LPME model input that normally controls the LPME model is used as follows to control the stand-alone HPME model. The stand-alone HPME model is invoked by setting NFDCAV = -1 on record FDInn00. For the stand-alone HPME model, there are two options for entering the debris source. The first option is to enter the debris source via the EDF package (see EDF package documentation) making normal use of NFDTPO on record FDInn00. The second option is to enter the debris source via tabular function input (see TF package documentation). The second option is invoked by setting NFDTPO = -N on record FDInn00, where N is the number of materials sourced in with separate tabular functions identified by records FDInnII. For the second option, the debris source temperature is entered via a tabular function, and the tabular function number is entered in NFDTPI on record FDInn00. The COR package must not be active when using the stand-alone HPME model.

Only the parameters that control the distribution of HPME debris throughout containment and the parameters that control the interaction of HPME debris with the containment atmosphere can be changed on restart in the MELCOR input. Therefore, it is important for users to determine which control volumes and deposition surfaces will be included in the data base at the time MELGEN is executed because volumes and surfaces cannot be added later.

2.1 MELGEN User Input

One set of the following records is required for each FDI location. (Up to 100 locations may be defined.) Input records FDInn00 and FDInn02 are required to activate either the LPME or HPME model, and, in addition, the FDInn04 and FDInnmm records are required to activate the HPME model.

Low-Pressure Model Input:

FDInn00 – FDI Location and Transfer Process Numbers
00 ≤ nn ≤ 99, nn is the FDI location number
Required

This record identifies the control volume, cavity, "in" transfer process number (for transfers to CORCON) and "out" transfer process number (for transfers from core) for each FDI location. NOTE: For stand-alone HPME model applications, NFDCAV, NFDTPI and NFDTPO have special meanings described below.

(1) NFDICV - User number of associated control volume
(type = integer, default = none, units = none)

(2) NFDCAV - User number of associated cavity
(type = integer, default = none, units = none)

NOTE: The stand-alone HPME model is invoked by setting NFDCAV = -1.

(3) NFDTPI - "In" transfer process number ('nnn' on the TPINnnn00 RECORD), for transfers to CORCON. For more details, see below. If NFDCAV = -1, set NFDTPI = N, where N is the tabular function number for the table of source temperature versus time. If an external data file (EDF) is used for the stand-alone HPME source, then set NFDTPI = -1.
(type = integer, default = none, units = none)

(4) NFDTPO - "Out" transfer process number ('nnn' on the TPOTnnn00 RECORD), for transfers from the core or EDF. For more details,

see below. If NFDCAV = -1, set NFDTPO = -N, where N is the number of source materials entered with separate tabular functions. If the EDF option is invoked, this entry has its normal definition.
(type = integer, default = none, units = none)

Material is transferred from the COR package (or an EDF file in the stand-alone HPME application) to the FDI package and from the FDI package to the CAV package through the Transfer Process (TP) package. The user must define transfer processes (in the TP package input) to perform the transfers. For transferring material from COR to FDI, an "in" transfer process must be defined to transfer material into the TP package from the COR package, and entered (as NTPCOR) on the COR00004 record in the COR package input. A corresponding "out" transfer process, with number NFDTPO (above), must be defined to take material out of the TP package and transfer it into the FDI package. Transfers between FDI and CAV are performed similarly. They involve the "in" process NFDTPI (above) and an "out" process entered as NTPOT on the CAVnnTP record in the CAV package input. If desired, material may be transferred directly from the COR package to the CAV package, bypassing the FDI package.

For transfers from FDI to CAV, the number of masses and the number of thermodynamic variables on the TPINnnn00 record (where nnn is NFDTPI) must be NMSIN = 5 and NTHRM = 9. Also, on the corresponding TPMnnn0000 record, the input must be NCOL = 5. The order of masses ejected from the FDI package (to be used when generating the translation matrix in the corresponding TPMnnnkkkk records) is:

(1) UO_2,

(2) Zr,

(3) steel,

(4) ZrO_2, and

(5) steel oxide.

Additional discussion of FDI-CAV transfers is included in the CAV Users' Guide.

IMPORTANT NOTE

In order to transfer the radionuclides along with the fuel and metal masses, additional transfer process numbers must be defined. Currently, these radionuclide TP numbers must be exactly 500 greater than the corresponding TP numbers defined for mass and energy transfers among the COR, FDI and CAV packages. The TP input should set the number of masses equal to the total number of radionuclide classes, NTHERM equal to 1, and should specify a unity translation matrix (DEF.1 on the TPOTnnn00 record).

FDInn01 – FDI Name
00 ≤ nn ≤ 99, nn is the FDI Location number
Optional

(1) FDINAM - Name of FDI Location.
(type = Character*16, default = ' ', units = none)

FDInn02 – Elevations
00 ≤ nn ≤ 99, nn is the FDI location number
Required

This record specifies the elevation at which material begins undergoing the FDI (usually, this will be the elevation of the bottom head penetration) and the elevation of the floor on which the material is deposited after the FDI is completed.

(1) ZBOTTM - Floor elevation. Must lie within the control volume identified by NFDICV on record FDInnn00. If not coincident with the bottom of that volume, a warning message will be issued.
(type = real, default = none, units = m)

(2) ZTOP - Top elevation of interaction region. Must be greater than ZBOTTM. If above the top of the associated control volume, a warning message will be issued.
(type = real, default = none, units = m)

<u>High-Pressure Model Input:</u>

FDInn04 – HPME Model Information
00 ≤ nn ≤ 99, nn is the FDI location number
Optional

The inclusion of this record activates the HPME model. This record is required if NFDCAV = -1 on record FDInn00. The sum of FATM and FDEP over all the volumes and surfaces associated with each FDI location must equal one or an error message will be issued.

(1) NATM - Number of control volumes HPME debris enters for this FDI location.
(type = integer, default = none, units = none)

(2) NDEP - Number of deposition surfaces associated with this FDI location by either settling or direct deposition from the HPME source.
(type = integer, default = none, units = none)

FDInnII – HPME Source Information

$00 \leq nn \leq 99$, nn is the FDI location number

$10 \leq II \leq 10+|NFDTPO|-1$, one card for each of the $|NFDTPO|$ material sources

Required if NFDTPO < 0 on record FDInn00

These records describe the materials sourced into the stand-alone HPME model by tabular function input. The tabular function should be the total mass of the specified material sourced in to the specified table time (integral of the mass source rate).

(1) MATNAM - Source material name.
(type = character, default = none, units = none)

(2) ITABLE - Tabular function number for material source MATNAM.
(type = integer, default = none, units = none)

Valid Entries for MATNAM:

(NOTE: Entries are case insensitive.)

Zircaloy
zirconium-oxide
uranium-dioxide
stainless-steel
stainless-steel-oxide
boron carbide
silver-indium-cadmium
uranium-metal
aluminum
aluminum-oxide
cadmium

FDInnmm – HPME Control Volume Parameters

$00 \leq nn \leq 99$, nn is the FDI location number

$50 \leq mm \leq 50+NATM-1$, one card for each of the NATM volumes

Required if FDInn04 record entered

(1) IDATM - User number of CVH volume receiving debris.
(type = integer, default = none, units = none)

(2) IFLR - User number of HS surface or CAV cavity debris will settle onto from volume IDATM.
(type = integer, default = none, units = none)

(3) ITYP - Character string which indicates what type of surface IFLR is.

'CAV' for CORCON cavity
'LHS' for left-hand side of HS structure
'RHS' for right-hand side of HS structure
(type = character, default = none, units = none)

(4) FATM - Fraction of debris ejected from location nn that enters atmosphere of control volume IDATM.
(type = real, default = none, units = none)

(5) TOXV - Time constant for oxidation reactions in the atmosphere of control volume IDATM. The time constant will have a value equal to the absolute value of TOXV. A positive value for TOXV indicates that a hierarchical scheme will be used in which the order of oxidation is Zr, Al then steel. A negative value of TOXV indicates that oxidation of all metals will occur simultaneously.
(type = real, default = none, units = s)

(6) THT - Time constant for heat transfer to the atmosphere of control volume IDATM.
(type = real, default = none, units = s)

(7) TST - Time constant for settling onto surface IFLR from control volume IDATM.
(type = real, default = none, units = s)

NOTE: Time constants with absolute values smaller than 10^{-6} s will be reset to 10^{-6} s to avoid numerical problems.

FDInnkk – HPME Deposition Surface Parameters
$00 \leq nn \leq 99$, nn is the FDI location number
$50+NATM \leq kk \leq 50+NATM+NDEP-1$, one card for each NDEP surface
NOTE: kk continues where mm finished from preceding records.
Required if FDInn04 record entered.

These records describe the surfaces that debris is deposited onto from both settling (from control volumes) and/or direct deposition from the HPME source.

(1) IDDEP - User number of HS surface or CAV cavity that receives debris from settling and/or direct deposition from the HPME source.
(type = integer, default = none, units = none)

(2) ITYP - Character string which indicates what type of surface IDDEP is.
'CAV' for CORCON cavity
'LHS' for left-hand side of HS structure

'RHS' for right-hand side of HS structure
(type = character, default = none, units = none)

(3) FDEP - Fraction of debris ejected from location nn which is deposited directly on surface IDDEP (independent of settling from control volumes).
(type = real, default = none, units = none)

If ITYP = 'LHS' or 'RHS', then

(4) TOXS - Time constant for oxidation reactions on surface IDDEP. The time constant will have a value equal to the absolute value of TOXS. A positive value of TOXS indicates that a hierarchical scheme will be used in which the order of oxidation is Zr, Al then steel. A negative value of TOXS indicates that oxidation of all metals will occur simultaneously.
(type = real, default = none, units = s)

Otherwise, if ITYP = 'CAV', then

(4) NFDITP - "In" transfer process number associated with the deposition process to a CORCON cavity.
This record is only read if ITYP = 'CAV'.
(type = integer, default = none, units = none)

2.2 MELCOR User Input

The FDInn04, FDInnmm, and FDInnkk records may be modified on restart.

FDInn04 – HPME Model Information
$00 \leq nn \leq 99$, nn is the FDI location number
Optional

Only control volumes and deposition surfaces that were initially defined in the data base may be modified, so that the values of NATM and NDEP must not exceed their MELGEN values. The sum of FATM and FDEP over all volumes and surfaces associated with FDI location nn must be equal to one or an error message will be issued.

(1) NATM - Number of control volumes to be modified.
(type = integer, default = none, units = none)

(2) NDEP - Number of deposition surfaces to be modified.
(type = integer, default = none, units = none)

FDInnmm – HPME Control Volume Parameters

00 ≤ nn ≤99, nn is the FDI location number
50 ≤ mm ≤ 50+NATM-1, one card for each modified volume
Required if FDInn04 record entered

(1) IDATM - User number of modified CVH volume.
(type = integer, default = none, units = none)

(2) IFLR - User number of HS surface or CAV cavity debris will settle onto from volume IDATM.
(type = integer, default = none, units = none)

(3) ITYP - Character string which indicates what type of surface IFLR is.
'CAV' for CORCON cavity
'LHS' for left-hand side of HS structure
'RHS' for right-hand side of HS structure
(type = character, default = none, units = none)

(4) FATM - Fraction of ejected debris that enters atmosphere of control volume IDATM.
(type = real, default = none, units = none)

(5) TOXV - Time constant for oxidation reactions in the atmosphere of control volume IDATM. The time constant will have a value equal to the absolute value of TOXV. A positive value for TOXV indicates that a hierarchical scheme will be used in which the order of oxidation is Zr, Al then steel. A negative value of TOXV indicates that oxidation of all metals will occur simultaneously.
(type = real, default = none, units = s)

(6) THT Time constant for heat transfer to the atmosphere of control volume IDATM.
(type = real, default = none, units = s)

(7) TST - Time constant for settling onto surface IFLR from control volume IDATM.
(type = real, default = none, units = s)

NOTE: Time constants with absolute values smaller than 10^{-6} s will be reset to 10^{-6} s to avoid numerical problems.

FDInnkk – HPME Deposition Surface Parameters

00 ≤nn ≤ 99, nn is the FDI location number
50+NATM ≤ kk ≤ 50+NATM+NDEP-1, one card for each modified surface

NOTE: kk continues where mm finished from preceding records.
Required if FDINN04 record entered.

These records are used to modify the values of FDEP.
NFDIP cannot be modified on restart and does not appear.

(1) IDDEP - User number of modified surface.
(type = integer, default = none, units = none)

(2) ITYP - Character string which indicates what type of surface IDDEP is.
'CAV' for CORCON cavity
'LHS' for left-hand side of HS structure
'RHS' for right-hand side of HS structure
(type = character, default = none, units = none)

(3) FDEP - Fraction of ejected debris which is deposited directly on surface IDDEP (independent of settling from control volumes).
(type = real, default = none, units = none)

If ITYP = 'LHS' or 'RHS', then

(4) TOXS - Time constant for oxidation reactions on surface IDDEP. The time constant will have a value equal to the absolute value of TOXS. A positive value of TOXS indicates that a hierarchical scheme will be used in which the order of oxidation is Zr, Al then steel. A negative value of TOXS indicates that oxidation of all metals will occur simultaneously.
(type = real, default = none, units = s)

3. Sensitivity Coefficients

The *sensitivity coefficient* feature in MELCOR is a powerful feature that gives the user the ability to change selected parameters the physics models that would otherwise require modification of the Fortran source code. Their use is described in Section 7 of the the MELCOR EXEC Users' Guide.

3.1 FDI Sensitivity Coefficients

4602 – High/Low Ejection Velocity Transition

Vessel ejection velocity at transition between high and low pressure ejection modeling. The ejection velocity calculated in the COR package is compared to this coefficient to determine whether to invoke the high- or low-pressure model.
(default = 10., units = m/s, equiv = none)

4603 – Airborne Debris Temperature Limit

If the airborne debris temperature exceeds this value, then any oxidation energy is deposited directly into the atmosphere to simulate the effect of a rapid increase in debris-to-gas heat transfer caused by debris fragmentation associated with rapidly escalating internal vapor pressure above the debris boiling point.
(default = 3700., units = K, equiv = none)

4604 – Maximum Change in CVH Atmosphere Temperature per Timestep

If direct containment heating will change the CVH atmosphere temperature by more than this value in a single timestep, then the FDI package will request a timestep fallback.
(default = 500., units = K, equiv = none)

4605 – Pool Water Ejection Ratio

Proportionality constant between the mass of water ejected from the cavity pool and the mass of debris injected into the pool from the HPME source. If X kg of debris is ejected from the COR package in a timestep, then X*C4605(1) kg of pool water is transferred to the fog component of the reactor cavity atmosphere during that timestep.
(default = 10., units = none, equiv = none)

4606 – Minimum Airborne Mass Ratio

The ratio of the current airborne mass to the integrated airborne debris mass source in a control volume below which the mass will be deposited onto the settling surface associated with the control volume – deactivates direct containment heating when the airborne mass remaining in a control volume becomes negligible.
(default = 0.001, units = none, equiv = none)

4607 – Initial Timestep Size for HPME initiation

If the current timestep size exceeds this value, at HPME model initiation, then the FDI package will request a timestep fallback.
(default = 0.0001, units = s, equiv = DTHPME)

4608 – Maximum Debris-to-Wall Heat Transfer Coefficient

The rate of heat transfer from deposited debris to the deposition surface is determined by a heat transfer time constant which is equal to MIN(0.5*TOXS,.001). The intention is to establish equilibrium between the debris temperature and the surface temperature on a reasonably short time scale. However, as the amount of

deposited debris accumulates, this can result in a very large heat flux to the surface. This sensitivity coefficient limits the rate of heat transfer if that value exceeds $HTC_{MAX} * A_{SRF}(T_{OLD} - T_{SRF})$, where HTC_{MAX} is the value of sensitivity coefficient 4608, A_{SRF} is the surface area of the deposition surface, T_{OLD} is the temperature of the deposited debris at the beginning of the timestep and T_{SRF} is the deposition surface temperature (from the Heat Structures package data base).
(default = 1000., units = W/m^2-K, equiv = HTCMAX)

4609 – Minimum Debris Temperature for Oxidation

The temperature of the debris (either airborne or deposited) must exceed this value, or oxidation of the metallic components of the debris is not permitted.
(default = 600., units = K, equiv = TOXMIN)

4610 – Oxygen/Steam Oxidation Weighting Factor

Weighting factor to control relative oxidation of debris by oxygen versus steam. The default value of 0.5 will give equal weighting proportional to their relative mole fractions in the atmosphere. A value of 0.0 will result in oxidation using all available steam in preference to oxygen, and a value of 1.0 will result in oxidation by available oxygen in preference to steam.
(default = 0.5, units = none, equiv = none)

4. Plot Variables and Control Function Arguments

The FDI package variables that may be used for plot variables and control function arguments are listed and described below. The control function arguments are denoted by a 'c'. The plot variable arguments are denoted by a 'p'. The 'c' or 'p' characters are inside slashes '/' following the variable name. In the following list n refers to the FDI location number and m refers to the CVH user volume numbers associated through MELGEN input with FDI location n.

FDI-FMREL.n	/cp/	Mass of material released to CORCON from FDI location n for this timestep. (kg)
FDI-FMRELT.n	/cp/	Integrated mass released to CORCON from FDI location n for entire calculation. (kg)
FDI-ETRAN.n	/cp/	Energy transferred to water from FDI location n for this timestep. (J)

FDI-ETRANT.n	/cp/	Integrated energy transferred to water from FDI location n for entire calculation. (J)
FDI-STGEN.n	/cp/	Mass of steam generated in FDI location n for this timestep. (kg)
FDI-STGENT.n	/cp/	Integrated steam mass generation for FDI location n for entire calculation. (kg)
FDI-ZR-OXRAT.n.m	/cp/	Zircaloy oxidation rate in CVH volume m for FDI location n. (kg/s)
FDI-ZR-OXTOT.n.m	/cp/	Integral over time of the Zircaloy oxidation rate in CVH volume m for FDI location n. (kg)
FDI-AL-OXRAT.n.m	/cp/	Aluminum oxidation rate in CVH volume m for FDI location n. (kg/s)
FDI-AL-OXTOT.n.m	/cp/	Integral over time of the aluminum oxidation rate in CVH volume m for FDI location n. (kg)
FDI-SS-OXRAT.n.m	/cp/	Steel oxidation rate in CVH volume m for FDI location n. (kg/s)
FDI-SS-OXTOT.n.m	/cp/	Integral over time of the steel oxidation rate in CVH volume m for FDI location n. (kg)
FD-O2-OXRAT.n.m	/cp/	Oxygen consumption rate in CVH volume m for FDI location n. (kg/s)
FDI-O2-OXTOT.n.m	/cp/	Integral over time of the oxygen consumption rate in CVH volume m for FDI location n. (kg)
FDI-ST-OXRAT.n.m	/cp/	Steam consumption rate in CVH volume m for FDI location n. (kg/s)
FDI-ST-OXTOT.n.m	/cp/	Integral over time of the steam consumption rate in CVH volume m for FDI location n. (kg)

FDI-H2-OXRAT.n.m	/cp/	Hydrogen generation rate in CVH volume m for FDI location n. (kg/s)
FDI-H2-OXTOT.n.m	/cp/	Integral over time of the hydrogen generation rate in CVH volume m for FDI location n. (kg)
FDI-ATM-POWR.n.m	/cp/	Heat transfer rate to atmosphere in CVH volume m for FDI location n. (W)
FDI-ATM-HEAT.n.m	/cp/	Heat transferred to atmosphere in CVH volume m for FDI location n. (J)
FDI-DEBRIS-T.n.m	/cp/	Airborne debris temperature in CVH volume m for FDI location n. (k)
FDI-OX-ENRGY.n.m	/cp/	Energy generated by the oxidation of Zircaloy and steel in CVH volume m for FDI location n. (J)
FDI-MASS-ADD.n.m	/cp/	Mass transferred from TP package to CVH volume m for FDI location n. (kg)
FDI-ENTH-ADD.n.m	/cp/	Enthalpy transferred from TP package to CVH volume m for FDI location n. (J)
FDI-ATM-ZRM.n.m	/cp/	Airborne mass of Zircaloy in CVH volume m for FDI location n. (kg)
FDI-ATM-ZRX.n.m	/cp/	Airborne mass of ZrO_2 in CVH volume m for FDI location n. (kg)
FDI-ATM-UO2.n.m	/cp/	Airborne mass of UO_2 in CVH volume m for FDI location n. (kg)
FDU-ATM-SSM.n.m	/cp/	Airborne mass of steel in CVH volume m for FDI location n. (kg)
FDI-ATM-SSX.n.m	/cp/	Airborne mass of steel oxide in CVH volume m for FDI location n. (kg)

FDI-ATM-ALM.n.m	/cp/	Airborne mass of aluminum in CVH volume m for FDI location n. (kg)
FDI-ATM-ALX.n.m	/cp/	Airborne mass of Al_2O_3 in CVH volume m for FDI location n. (kg)
FDI-ATM-UMT.n.m	/cp/	Airborne mass of uranium metal in CVH volume m for FDI location n. (kg)
FDI-ATM-CDM.n.m	/cp/	Airborne mass of cadmium in CVH volume m for FDI location n. (kg)
FDI-ATM-B4C.n.m	/cp/	Airborne mass of boron carbide in CVH volume m for FDI location n. (kg)
FDI-ATM-AIC.n.m	/cp/	Airborne mass of Ag-In-Cd in CVH volume m for FDI location n. (kg)
FDI-ATM-ALL.n.m	/p/	Airborne mass of all components in CVH volume m for FDI location n. (kg)
FDI-ZR-SXRAT.s.n.k	/cp/	Zircaloy oxidation rate on the s side of HS structure k for FDI location n. (kg/s)
FDI-ZR-SXTOT.s.n.k	/cp/	Integral over time of the Zircaloy oxidation rate on the s side of HS structure k for FDI location n. (kg)
FDI-AL-SXRAT.s.n.k	/cp/	Aluminum oxidation rate on the s side of HS structure k for FDI location n. (kg/s)
FDI-AL-SXTOT.s.n.k	/cp/	Integral over time of the aluminum oxidation rate on the s side of HS structure k for FDI location n. (kg)
FDI-SS-SXRAT.s.n.k	/cp/	Steel oxidation rate on the s side of HS structure k for FDI location n. (kg/s)
FDI-SS-SXTOT.s.n.k	/cp/	Integral over time of the steel oxidation rate on the s side of HS structure k for FDI location n. (kg)

FDI-O2-SXRAT.s.n.k	/cp/	Oxygen consumption rate on the s side of HS structure k for FDI location n. (kg/s)
FDI-O2-SXTOT.s.n.k	/cp/	Integral over time of the oxygen consumption rate on the s side of HS structure k for FDI location n. (kg)
FDI-ST-SXRAT.s.n.k	/cp/	Steam consumption rate on the s side of HS structure k for FDI location n. (kg/s)
FDI-ST-SXTOT.s.n.k	/cp/	Integral over time of the steam consumption rate on the s side of HS structure k for FDI location n. (kg)
FDI-H2-SXRAT.s.n.k	/cp/	Hydrogen generation rate on the s side of HS structure k for FDI location n. (kg/s)
FDI-H2-SXTOT.s.n.k	/cp/	Integral over time of the hydrogen generation rate on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-POWR.s.n.k	/cp/	Heat transfer rate to the s side of HS structure k for FDI location n. (W)
FDI-SRF-HEAT.s.n.k	/cp/	Heat transferred to the s side of HS structure k for FDI location n. (J)
FDI-TBD-SURF.s.n.k	/cp/	Temperature of deposited debris on the s side of HS structure k for FDI location n. (K)
FDI-SX-ENRGY.s.n.k	/cp/	Energy generated by the oxidation of metals on the s side of HS structure k for FDI location n. (J)
FDI-MASS-SET.s.n.k	/cp/	Total mass that has settled out of the atmosphere onto the s side of HS structure k for FDI location n. (kg)
FDI-ENTH-SET.s.n.k	/cp/	Total enthalpy that has settled out of the atmosphere onto the s side of HS structure k for FDI location n. (J)
FDI-SRF-ZRM.s.n.k	/cp/	Mass of Zircaloy on the s side of HS structure k for FDI location n. (kg)

FDI-SRF-ZRX.s.n.k	/cp/	Mass of ZrO_2 on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-UO2.s.n.k	/cp/	Mass of UO_2 on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-SSM.s.n.k	/cp/	Mass of steel on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-SSX.s.n.k	/cp/	Mass of steel oxide on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-ALM.sn.k	/cp/	Mass of aluminum on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-ALX.s.n.k	/cp/	Mass of Al_2O_3 on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-UMT.s.n.k	/cp/	Mass of uranium metal on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-CDM.s.n.k	/cp/	Mass of cadmium on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-B4C.s.n.k	/cp/	Mass of boron carbide on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-AIC.s.n.k	/cp/	Mass of Ag-In-Cd on the s side of HS structure k for FDI location n. (kg)
FDI-SRF-ALL.s.n.k	/p/	Mass of all components on the s side of HS structure k for FDI location n. (kg)

5. Example Input

The following input records define a single FDI location. In this example, the FDI location is labeled 15. It interfaces with control volume 210 and cavity 50. The corresponding transfer process input is also shown to help clarify the required input. Material is

transferred from the core to FDI through "in" transfer process 101 and "out" transfer process 101. Material is transferred from FDI to CORCON through "in" transfer process 102 and "out" transfer process 102. Note that any control poison (material 6) that is transferred from COR to TP is eliminated by Transfer Matrix 103 before reaching FDI. See the CPR, CAV, and TP Users' Guides for more information. The radionuclides are transferred through transfer processes 601 and 602 (INFDTPO+500 and NFDTPI+500, respectively). NOTE: Because the FDI1504 and FDI15NN records are absent, this input invokes the LPME model only.

```
***** FDI PACKAGE INPUT *****
* NFDICV NFDCAV NFDTPI NFDTPO
FDI1500 210 50 102 101
* ZBOTTM ZTOP
FDI1502  -5.  0.

***** COR AND CAV PACKAGE INPUT *****
* NTPCOR
COR00004 101
* NTPOT
CAV50TP 102
***** TP INPUT *****
* NMSIN NTHRM
TPIN10100  6  9
TPIN10200  5  9
* NMSOT NPOTOI IOTMTX
TPOT10100  5  101  UIN.103
TPOT10200  5  102  DEF.1
* NROW NCOL
TPM10300  5  6
* NROW/NCOL VALUE
TPM1030001  1/1  1.0
TPM1030002  2/2  1.0
TPM1030003  3/3  1.0
TPM1030004  4/4  1.0
TPM1030005  5/5  1.0
*             RADIONUCLIDE TRANSFER PROCESSES
TPIN60100  16  1
TPIN60200  16  1
*
TPOT60100  16  601  DEF.1
TPOT60200  16  602  DEF.1
```

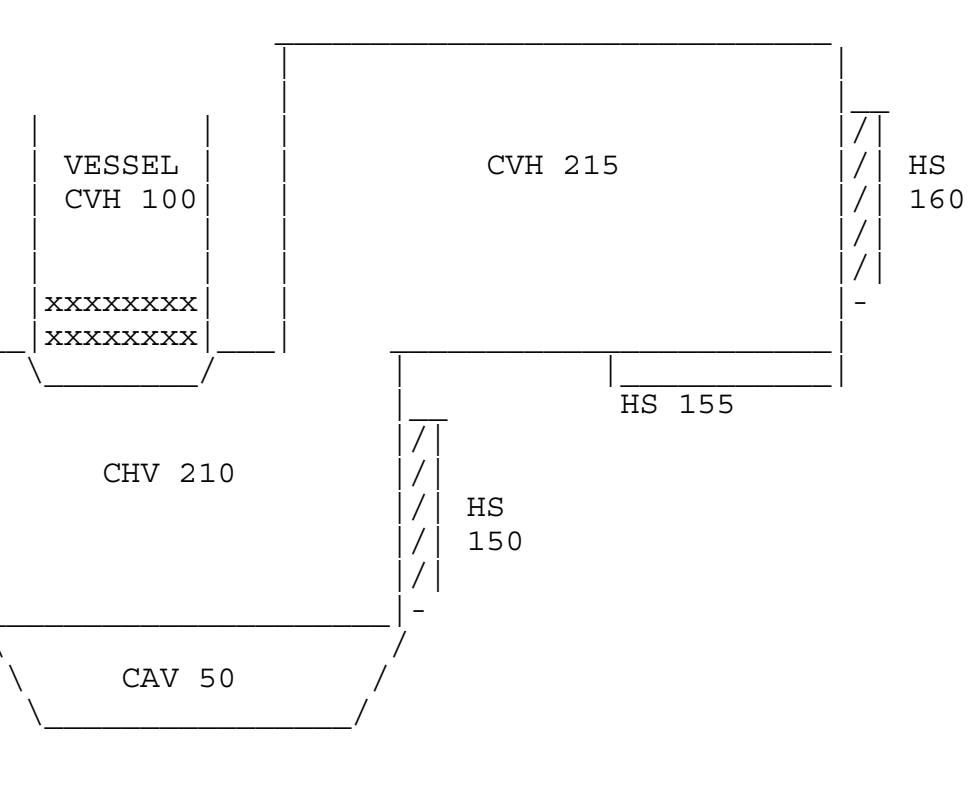
The next example shows how to invoke the stand-alone HPME model. Note the use of the EDF input for the debris source and the MP input to define the composition of the steel.

```
*****EXTERNAL DATA FILE PACKAGE INPUT *****
*
```

```
EDF00100 DCH-DATA 15 READ  *  READ FROM EXTERNAL DATA FILE
EDF00101 DCHDATA
     *  EDF FILE IS NAMED DCHDATA
EDF00102  '(8E9.3)'           * FORMAT OF DATA IN DCHDATA
*
***** TP INPUT *****
*
* 'IN'  TRANSFER PROCESS FROM EDF PACKAGE
TPIN10100  5  9     *  5 MATERIALS,  9 AUX.  VARIABLES
TPIN10101 READ 1  *  READ DCH SOURCE FROM EDF FILE 1
* 'OUT' TRANSFER PROCESS TO FDI PACKAGE
TPOT10200  5  101  DEF.1  *  USE MATRIX DEF.1 ON TP101
*
***** FDI INPUT *****
*
* NFDICV NFDCAV NFDTPI  NFDTPO
FDI0100  300  -1  -1  102  * INVOKE STAND-ALONE
* NAME
FDI0101  CVH300/HS20001    * MAKEUP A NAME
* ZBOTTM ZTOP
FDI0102  0.0  5.0          * ANY TWO REAL VALUES OK
* NATM NDEP
FDI0104  1  1
*IDATM IFLR  ITYP FATM TOXV  THT  TST
FDI0150  300  20001  LHS 1.0  3.E-1  2.E-1  1.E20
* IDDEP ITYP  FDEP  TOXS
FDI0151  20001 LHS  0.0  1.E1
*
*****  MP INPUT  *****
*
MPMAT00600 'STEEL'
*
MPMAT00699  1.0  0.0  0.0  0.0     * 100% FE, no CR, NI, or C
```

The final example shows how the FDI input from the first example can be expanded to activate the normal HPME model. If CVH 210 represents the reactor cavity volume with associated CORCON cavity 50, the LPME model input in the first example is perfectly reasonable. However, if the reactor vessel were to fail at high pressure there is a possibility that some of the ejected debris could be blown out of the reactor cavity into the upper containment, in which case HPME model input must be included to treat the situation reasonably. Assume that the nuclear power plant under investigation has been nodalized as depicted in the diagram below. Furthermore, assume that 60% of the ejected debris is deposited directly in the molten pool that forms at the bottom of the rector cavity (CAV 50), 30% splashes into the atmosphere but remains within the reactor cavity (CVH 210), 1% is deposited on the walls of the reactor cavity (HS 150) and of the 9% that escapes from the reactor cavity 4% is deposited directly on the walls of the upper

containment (HS 160) while the remaining 5% is dispersed throughout the upper containment atmosphere. Appropriate values for the time constants for oxidation, heat transfer and settling in CVH 210 and CVH 215 can be obtained in basically two ways—through analysis of the results of an independent DCH calculation of the problem or through simple hand calculations based upon reasonable assumptions concerning containment geometry dimensions, particle size and transfer coefficients (see FDI package Reference Manual). Assume values of 0.1 s have been obtained for the oxidation and heat transfer time constants, while a value of 1 s was obtained for the settling time constant. Then the appropriate LPME and HPME input would appear as follows:




```
***** FDI PACKAGE INPUT  *****
* NFDICV NFDCAV NFDTPI NFDTPO
FDI1500  210  50  102  101
* ZBOTTM ZTOP
FDI1502  -5.  0.
* NATM NDEP
FDI1504  2  4
*          IDATM     IFLR  ITYP  FATM   TOXV    THT    TST
FDI1550    210         50   CAV  .30    1.E-1   1.E-1  1.E-0
*          IDATM     IFLR   ITYP FATM   TOXV    THT    TST
FDI1551    215       155    LHS  .05    1.E-1   1.E-1  1.E-0
*          IDDEP     ITYP   FDEP NFDITP
```

```
FDI1552    50        CAV    0.60 102    * DIRECT DEP. AND SETTLING
*          IDDEP     ITYP   FDEP TOXS
FDI1553    150       LHS    .01  1.E1
*          IDDEP     ITYP   FDEP TOXS
FDI1554    155       LHS    0.0  1.E1
*          IDDEP     ITYP   FDEP TOXS
FDI1555    160       LHS    .04  1.E1
```

As might be expected the "in" transfer process number for the HPME model (NFDITP) is the same as the number associated with the LPME model (NFDTPI) since they transfer material to the same CORCON cavity. Notice that the left-hand side of heat structures 150, 155 and 160 do not and cannot have values of NFDITP associated with them. It is assumed that HS input will be included to properly orient the left hand sides of structures 150, 155 and 160 with respect to volumes 210 and 215.

In the absence of better information for deriving appropriate time constants for oxidation, heat transfer and settling for airborne debris, values for these parameters may be estimated as discussed in the following sections.

5.1 Settling time constant

The settling time constant in volume *i*, *TST(i)*, may be approximated as

$$TST(i) = L(i)/V(i)$$

where

L(i) = settling height in volume i (m)

V(i) = settling velocity in volume i (m/s)

The settling height is limited to the maximum ceiling height in volume i but may be less if the injected debris is not expected to reach that height for some reason. The settling velocity may be estimated from the lesser of the value from an appropriate correlation for the terminal velocity of falling bodies and

$$\left[2\, L(i) / g\right]^{0.5} ,$$

where g is the acceleration of gravity. Typical values of *L(i)* and *V(i)* would be on the order of 1 to 10 m and 1 to 10 m/s, respectively. Consequently, *TST(i)* is expected to be on the order of 1 s.

5.2 Heat transfer time constant

The heat transfer time constant in volume *i*, *THT(i)*, may be approximated as

$$THT(i) = RHOD \times CPD \times D / (6 \times H)$$

where

RHOD = density of debris (kg/m^3)

CPD = specific heat capacity of debris (J/kg-K)

D = equivalent spherical diameter of debris particles (m)

H = debris-to-gas heat transfer coefficient (W/m^2-K)

Typically, *RHOD* is on the order of 10,000 kg/m^3, *CPD* is on the order of 500 J/kg-K, *D* is on the order of 0.001 m and *H* is on the order of 1000 W/m^2-K. Hence, *THT(i)* is expected to be on the order of 0.5 s.

5.3 Oxidation time constant

Assuming the oxidation rate is limited primarily by mass transfer in the gas phase and applying the analogy between heat and mass transfer rates in turbulent flow, it is expected that the oxidation time constant in volume *i*, *TOX(i)*, will be approximately equal to *THT(i)*.

NOTE: Because of the uncertainties associated with the values of *TST(i)*, *THT(i)*, *TOX(i)* and most of the phenomena affecting direct containment heating, it is recommended that users conduct sensitivity studies by varying the assumed values of the HPME model input, if the results of a calculation concerning DCH do not conclusively resolve the issues of primary importance.

6. Diagnostic and Error Messages

The FDI package prints a message if any of the following occur:

(1) an error is detected during MELGEN input processing

(2) an error is detected during MELCOR input processing

(3) the HPME model becomes active

(4) direct containment heating begins in a volume

(5) the ejection velocity drops sufficiently to switch from the HPME model to the LPME model

(6) direct containment heating ceases in a volume due to settling

(7) FDI requests repeating a MELCOR cycle with a smaller timestep due to excessive predicted CVH atmosphere temperature change

The following examples were extracted from MELCOR files:

(from MELGEN diagnostics file)

*** ERROR IN SUBROUTINE FDIP2 ***

SUM OF ALL FATM AND FDEP NOT EQUAL ONE FOR FDI LOCATION 1

This message informs the user that there is an inconsistency in the specified debris distribution input on records FDInnmm (values of FATM) and FDInnkk (values of FDEP). As stated in the description of record FDInn04, the user is required to ensure that the sum of FATM and FDEP over all the volumes and surfaces associated with each FDI location is equal to one.

(from MELCOR message file)

/SMESSAGE/ CYCLE = 1011 TIME(S) = 9.14114E+03

COR0001: MESSAGE FROM CORE PACKAGE

LOWER HEAD PENETRATION 1 IN RADIAL RING 1 HAS FAILED

INITIAL DIAMETER OF HOLE IS 3.400E-02 M

COR0002: MEASSAGE FROM CORE PACKAGE

BEGINNING OF DEBRIS INJECTION TO CAVITY

***** FDI PACKAGE HPME MESSAGE *****

HIGH PRESSURE MELT EJECTION HAS BEGUN IN VOLUME 300

***** FDI PACKAGE HPME MESSAGE *****

DIRECT CONTAINMENT HEATING HAS BEGUN IN VOLUME 300

CAV0002 – MESSAGE FROM CAVITY PACKAGE

CAVITY 7 WAKING UP

/SMESSAGE/ CYCLE = 1061 TIME(S) = 9.14471E+03

***** FDI PACKAGE HPME MESSAGE *****

HPME HAS SWITCHED TO LPME IN VOLUME 300

/SMESSAGE/ CYCLE = 1078 TIME(S) = 9.14551E+03

CF0403 – MESSAGE FROM CONTROL FUNCTION PACCKAGE

CONTROL FUNCTION 403 – FAILURE MESSAGE BECAME .TRUE.

THE CONTAINMENT HAS FAILED FROM OVERPRESSURE

/SMESSAGE/ CYCLE = 1131 TIME(S) = 9.15098E+03

***** FDI PACKAGE HPME MESSAGE *****

DIRECT CONTAINMENT HEATING HAS CEASED IN VOLUME 300

These messages inform the user that:

(1) HPME began in control volume 300 immediately after lower head penetration 1 in radial ring 1 of the reactor vessel failed at cycle 1011 of the calculation,

(2) as a result of the HPME, direct containment heating began in control volume 300 at the same time,

(3) that approximately 4.6 seconds later the pressure in the reactor vessel was no longer sufficient to drive HPME, so that after that time all additional debris ejected from the vessel was treated by the LPME model, and

(4) by about 10 seconds after HPME began, most of the airborne debris ejected into the atmosphere of control volume 300 had settled onto deposition surfaces, so that direct containment heating had effectively ceased.

(from MELCOR diagnostics file)

***** FDI PACKAGE TIMESTEP CUT *****

CYCLE = 1026 TIME = 9.14131E+03 DT = 9.998E-02

This message informs the user that the FDI package cut the timestep at cycle 1026 (because of the rapid rate of heat transfer from direct containment heating) to avoid causing excessive change in the CVH atmosphere temperature.